# CHAPTER 7

# COST BENEFIT ANALYSIS

## 7-1. Introduction

This chapter provides guidelines to evaluate the cost effectiveness of upgrading seismically deficient existing buildings on the basis of data obtained from the preliminary evaluation, the detailed structural analyses, and the development of design concepts. Criteria are provided to determine the cost effectiveness of taking no action (i.e., leave "as is"), upgrading or replacement of existing deficient buildings.

## 7-2. Earthquake risk

Methodology for the specification of ground motion is provided by chapter 3 of the SDG.

*a. Probability of occurrence.* On the basis of available data and state-of-the-art techniques, estimates can be made on the probability of occurrence of earthquake motion at a particular site

*Table 7-1. Probabilities of exceedance of peak ground acceleration in 50 years, NAS Moffett Field, California*

**PROBABILITIES OF EXCEEDANCE OF PEAK GROUND ACCELERATION**

**IN 50 YEARS, NAS MOFFETT FIELD, CALIFORNIA**

| PGA'S | Probability of Exceedance |
|---|---|
| 0.0 | 1.0000 |
| 0.05 | .9990 |
| 0.1 | .9563 |
| 0.15 | .7698 |
| 0.2 | .5803 |
| 0.25 | .4452 |
| 0.3 | .3383 |
| 0.35 | .2571 |
| 0.4 | .1979 |
| 0.45 | .1518 |
| 0.5 | .1166 |
| 0.55 | .0901 |
| 0.6 | .0706 |
| 0.65 | .0542 |
| 0.7 | .0405 |
| 0.75 | .0310 |
| 0.8 | .0241 |
| 0.85 | .0179 |
| 0.9 | .0136 |
| 0.95 | .0101 |
| 1.00 | .0071 |

that is caused by a variety of earthquakes at different sources. The results of such a study can be summarized by a curve that plots number of occurrences per year that equal or exceed various levels of peak horizontal ground accelerations (PGA). An example of this relationship is shown in table 7-1.

*b. Response spectra for selected seismic events.* The various levels of earthquake ground motions that are postulated for a particular site during a selected period of time can be represented by a series of response spectra. For example, a set of response spectra, with appropriate damping values for elastic and post-yield responses, can be used to represent the earthquake demand for each of the PGA levels in table 7-1. The response spectra shown in figure 7-1 are normalized to 1.0g. These spectra can be used for any PGA level by selecting the appropriate damping levels and multiplying the spectral ordinates of the selected curves in the figure by the desired PGA level.

## 7-3. Damageability of the structure

The results of the preliminary evaluation as determined by the procedures in paragraph 4-2*d* will give an indication of the damageability of the structure. However, consideration should be given to the degree of accuracy used in the analysis of the structure. Due to the approximate nature of the damage estimate procedures, the results can sometimes be misleading. A review of the analysis should be made to determine if the amount of predicted damage has been overstated or understated. The results of the detailed analysis of chapter 5 can be used to more accurately describe the capacity of the structure, especially if method 2 was used.

*a. Capacity to resist earthquake without damage.* If the existing structure is able to conform to the acceptance criteria of paragraph 5-2, it is assumed that there will be no damage for EQ-I and little, if any, damage for EQ-II. The effects of EQ-I can be approximated by the damage control check

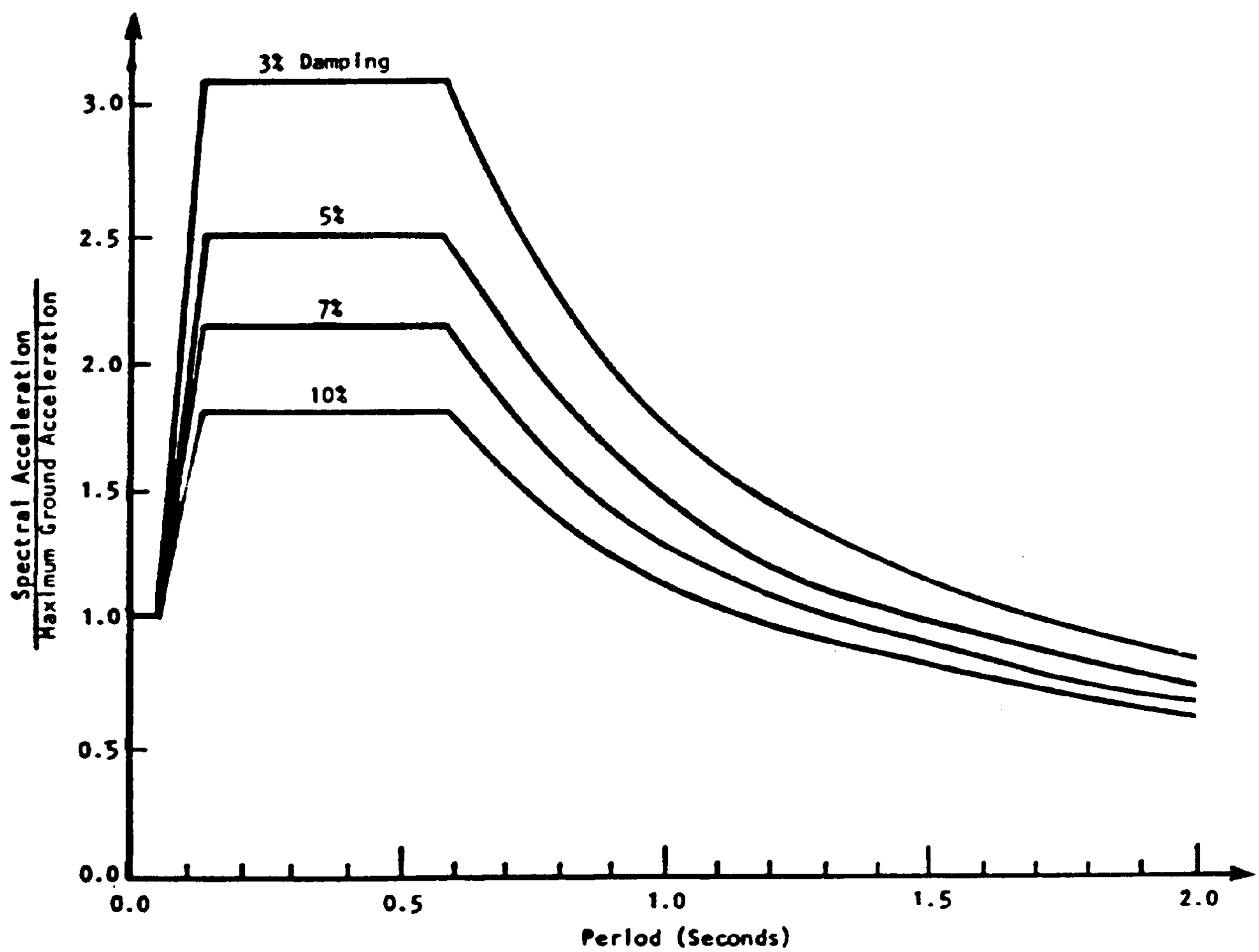


*Figure 7–1. Acceleration response spectra normalized to 1.0g.*

procedure described in paragraph 6-3*e*.

*b*. Repair costs. If the results of the detailed analysis indicate that damage will occur in the event of EQ-II, estimates will be made to establish costs to repair for the damage associated with each of a series of earthquake response spectra such as discussed in paragraph 7-2*b*. The repair costs may be based on the damage estimate procedure described in paragraph 4-2 using the capacity determined in the detailed analysis described in paragraph 5-4. If sufficient data are available, it is preferable to make a more rational estimate based on an itemized list of repairs. The list might include such items as painting and cosmetic repairs, repairs to partitions, repair cracks in concrete elements, replacement of steel braces, repairs to diaphragms and connections, repair to shear walls, and replacement of major structural elements. The methods and degree of effort used to make the cost estimates will be dependent on the size, type, and function of the structure.

## 7-4. Annualized repair costs without seismic upgrading

Actual costs for damage predictions are difficult to define. In addition to technical evaluations, there are also social, economic, and administrative decisions that should be considered. For example, after an earthquake occurs that causes some damage to a structure, four general courses of action may be available: do nothing; do minimum repair and/or modifications; do moderate repair and/or modifications that may upgrade the capacity of the structure; or tear down the structure and rebuild. A decision on the course of action must be made after each earthquake. A solution based on this sort of approach would require the use of decision theory; however, development of a methodology using decision theory has been considered to be too complex for use in this manual. To simplify the procedure, one decision was made that governs all the structures for any size earthquake. If will be assumed that after each earthquake, the building will be repaired to restore it to the pre-earthquake condition. The cost of such repairs is the damage cost determined in paragraph 7-3, above. A procedure to estimate the annualized repair costs and determine their present value is outlined below:

*a*. Select a series of ground motion response spectra that represent all postulated earthquakes as described in paragraph 7-2*b*.

*b*. Determine the number of seismic events represented by each of the above earthquake spectra during the useful life of the building. The useful life of an existing building will be assumed to be not less than 25 years, unless otherwise directed by the approval authority.

*c*. Estimate the repair costs for each of the earthquake spectrum in *a*, above.

*d*. Multiply each of the repair costs, estimated in *c* above, by the number of seismic events associated with each spectrum as determined in *b* above.

*e*. Calculate total repair costs, R, by totaling the repair costs for all the postulated earthquakes.

*f*. Obtain the annualized repair costs by dividing the total repair costs, R, by the time span, n, used in *b*, above.

*g*. Calculate the present value of the annualized repair costs by:

$$\text{PVR} = \sum R/n \left( \frac{1+j}{1+i} \right) \qquad \text{(eq 7-1)}$$

where PVR = Present value of annualized repair costs
R = Total repair costs during the useful life of the building
i = Assumed average interest rate for next n years
j = Assumed inflation rate for next n years
n = Useful life of the building (i.e., not less than 25 years, unless otherwise directed).

## 7-5. Cost of seismic upgrading

The recommended concepts developed in accordance with the guidelines of paragraph 6-3 will be used for estimating the costs of seismic upgraded buildings.

## 7-6. Annualized repair costs after seismic upgrading

The acceptance criteria specified in paragraph 5-2 imply that essential buildings conforming to these criteria will be subjected to minor damage from the ground motion associated with EQ-II, but the buildings will be capable of performing their essential functions with little or no interruption of these functions. For high-risk and all other buildings, the criteria imply that structural collapse will be precluded, but that some structural damage is to be expected. These criteria also imply acceptance of the risk of additional damage from ground motion more severe than that associated with EQ-II. The repair costs associated with this seismic damage to the recommended concepts will be calculated as described in paragraph 7-4, above, for the existing building models but with the new structural capacities resulting from the upgrading modifications.

## 7-7. Cost versus benefits of a recommended upgrading concept

*a. Cost of no action.* The present value of the annualized repair costs to the existing building will be determined by the procedures outlined in paragraph 7-4.

*b. Total costs of the recommended upgrading concept.* The total cost associated with the recommended concept will be the upgrading construction cost, determined in paragraph 7-5, plus the present value of the annualized repair costs determined in paragraph 7-6.

*c. Replacement costs.* The cost of constructing a new building to replace the existing building will be estimated. Since this cost will be used only for comparison with the costs determined in paragraphs *a* and *b* above, the same degree of refinement will be used. In most cases, the replacement cost may be determined from the inventory of real property (see para 2-2) or estimated from representative costs per square foot of similar construction in the area adjusted, as necessary for size, inflation, and other factors.

*d. Economic analysis.* An economic analysis of the above costs will be made by comparison of the various costs outlined in paragraphs *a*, *b*, and *c* above.

*e. Example.* An example of a cost benefit analysis, taken from a recent study performed under the auspices of the Naval Civil Engineering Laboratory (NCEL), is summarized in tables 7-2 and 7-3 and is described below.

(1) *Description of building.* The building is a two-story reinforced concrete structure designated as unaccompanied enlisted personnel housing (UEPH). The lateral force resisting system is comprised of the concrete roof and floor diaphragms and the reinforced concrete shear walls. The elastic capacity of the longitudinal shear walls occurs at a PGA of 0.39g. In the transverse direction, the elastic capacity occurs at a PGA of 0.12g and is limited to flexural yielding of short interior shear walls and their connecting grade beams.

(2) *Earthquake demand.* The seismic hazard at this site (NAS Moffett Field, California) is represented in table 7-1. Corresponding values of EQ-I and EQ-II would be about 0.23g and 0.57g respectively. The site response spectra, shown in figure 7-1, are normalized to a PGA of 1.0g.

(3) *Number of seismic events.* The useful life of this building was assumed to be 50 years. The number of seismic events, that can be expected during this 50 year period, equal to or exceeding a given PGA value, was calculated for PGA increments of 0.05g from the data in table 7-1 using the Poison probability relationships. The difference between the number of events for consecutive increments of PGA is designated as NEI in tables 7-2 and 7-3, and this difference represents the expected number of events of a severity bracketed by the two PGA levels (e.g., in table 7-2, the NEI value of 1.6616 represents the number of seismic events expected in 50 years with a PGA between 0.l0g and 0.15g).

(4) *Damage estimates.* Estimates of damage for each PGA increment were calculated using procedures similar to method 2 as described in paragraph 5-3*f*. For purposes of this study, the total damage was defined as:

$$DE = \frac{D_1 + D_2}{2} + D_3 + D_4 \leq RC \qquad \text{(eq 7-2)}$$

where
- DE = average total damage for a seismic event corresponding to a given PGA level at the site
- $D_1$ = total damage when full PGA is experienced in N/S direction and 0.75 PGA in E/W direction
- $D_2$ = total damage when full PGA is experienced in E/W direction and 0.75 PGA in N/S direction
- $D_3$ = damage to equipment which is uncoupled from building damage, except under collapse conditions, and related only to PGA
- $D_4$ = damage to contents which is uncoupled from building damage, except under collapse conditions, and related only to PGA
- RC = replacement cost of building and contents

(5) *Replacement and modification costs.* The building upon which this study was based contains 13,760 sq. ft. and has a current replacement cost of $1,106,000 plus contents valued at $97,600. A strengthening scheme was developed to increase the elastic capacity of the buiding in the transverse (north-south) direction to a level corresponding to a PGA of 0.20g. Strengthening is not required in the longitudinal (east-west) direction. The modified building would be substantially in compliance with the acceptance criteria of EQ-I and EQ-II and the estimated modification costs are $32,700.

(6) *Total cost of repairs.* The total damage, TD, in a PGA interval is defined as the average damage cost in the interval and is calculated by the number of events, NEI, multiplied by the average total damage per event, DE, for two successive PGA levels (e.g., in table 7-2, and TD value of $\$6{,}977 = 0.2791 \times \frac{15{,}000 + 35{,}000}{2})$. The averaging of the two DE values is required be-

*Table 7-2. Summary of a cost benefit study for an existing building without seismic upgrading*

| PGA | NEI | D1 | D2 | D3 | D4 | DE | TD |
|---|---|---|---|---|---|---|---|
| .05 | - | 0. | 0. | 0. | 0. | 0. | 0. |
| .10 | 3.7774 | 0. | 0. | 0. | 0. | 0. | 0. |
| .15 | 1.6616 | 4000. | 1000. | 1000. | 0. | 3500. | 2908. |
| .20 | .6006 | 20000. | 4000. | 2000. | 1000. | 15000. | 5555. |
| .25 | .2791 | 37000. | 17000. | 4000. | 4000. | 35000. | 6977. |
| .30 | .1762 | 65000. | 30000. | 8000. | 9000. | 64500. | 8766. |
| .35 | .1157 | 83000. | 47000. | 14000. | 14000. | 93000. | 9115. |
| .40 | .0767 | 112000. | 65000. | 23000. | 19000. | 130500. | 8568. |
| .45 | .0559 | 141000. | 113000. | 32000. | 23000. | 182000. | 8732. |
| .50 | .0407 | 170000. | 174000. | 41000. | 25000. | 238000. | 8539. |
| .55 | .0296 | 224000. | 236000. | 50000. | 27000. | 307000. | 8054. |
| .60 | .0212 | 663000. | 663000. | 186000. | 98000. | 947000. | 13295. |
| .65 | .0175 | 663000. | 663000. | 186000. | 98000. | 947000. | 16565. |
| .70 | .0144 | 663000. | 663000. | 186000. | 98000. | 947000. | 13619. |
| .75 | .0099 | 663000. | 663000. | 186000. | 98000. | 947000. | 9330. |
| .80 | .0071 | 663000. | 663000. | 186000. | 98000. | 947000. | 6719. |
| .85 | .0063 | 663000. | 663000. | 186000. | 98000. | 947000. | 5997. |
| .90 | .0044 | 663000. | 663000. | 186000. | 98000. | 947000. | 4137. |
| .95 | .0035 | 663000. | 663000. | 186000. | 98000. | 947000. | 3354. |
| 1.00 | .0030 | 663000. | 663000. | 186000. | 98000. | 947000. | 2866. |
| | | | | | | R = | 143097. |

DIFFERENTIAL RATE = 3.00%
INTEREST RATE = 8.00%
INFLATION RATE = 5.00%

CM = 0.
PVR = 77839.
TC = 77839.

NOTATION :

PGA = PEAK GROUND ACCELERATION IN G UNITS
NEI = NO. OF SEISMIC EVENTS BETWEEN PRIOR AND CURRENT PGA
D1 = STRUCTURAL & ARCHITECTURAL DAMAGE, N-S EARTHQUAKE
D2 = STRUCTURAL & ARCHITECTURAL DAMAGE, E-W EARTHQUAKE
D3 = ELECTRICAL & MECHANICAL EQUIPMENT DAMAGE
D4 = CONTENTS DAMAGE

DE = TOTAL DAMAGE PER EVENT
= (D1+D2)/2+D3+D4 WHERE (D1+D2)/2+D3+D4 < RC
TD = TOTAL DAMAGE IN THE PGA INTERVAL
= NEI*(PRIOR DE + CURRENT DE)/2
R = TOTAL COST OF FUTURE DAMAGE
RC = REPLACEMENT COST
CM = COST OF MODIFICATIONS
PVR = PRESENT VALUE OF COST OF FUTURE DAMAGE ASSUMING DAMAGE SPREAD UNIFORMLY OVER 50 YEAR PERIOD
TC = TOTAL COST
= PVR + CM

*Table 7–3. Summary of a cost benefit study of an existing building with seismic upgrading*

| PGA | NEI | D1 | D2 | D3 | D4 | DE | TD |
|---|---|---|---|---|---|---|---|
| .05 | - | 0. | 0. | 0. | 0. | 0. | 0. |
| .10 | 3.7774 | 0. | 0. | 0. | 0. | 0. | 0. |
| .15 | 1.6616 | 0. | 0. | 0. | 0. | 0. | 0. |
| .20 | .6006 | 0. | 0. | 0. | 1000. | 1000. | 300. |
| .25 | .2791 | 13000. | 0. | 1000. | 4000. | 11500. | 1744. |
| .30 | .1762 | 30000. | 8000. | 3000. | 9000. | 31000. | 3744. |
| .35 | .1157 | 60000. | 19000. | 7000. | 14000. | 60500. | 5296. |
| .40 | .0767 | 90000. | 30000. | 13000. | 19000. | 92000. | 5846. |
| .45 | .0559 | 120000. | 88000. | 22000. | 23000. | 149000. | 6734. |
| .50 | .0407 | 150000. | 152000. | 31000. | 25000. | 207000. | 7238. |
| .55 | .0296 | 194000. | 216000. | 40000. | 27000. | 272000. | 7079. |
| .60 | .0212 | 244000. | 696000. | 126000. | 66000. | 662000. | 9903. |
| .65 | .0175 | 696000. | 696000. | 186000. | 98000. | 980000. | 14361. |
| .70 | .0144 | 696000. | 696000. | 186000. | 98000. | 980000. | 14094. |
| .75 | .0099 | 696000. | 696000. | 186000. | 98000. | 980000. | 9655. |
| .80 | .0071 | 696000. | 696000. | 186000. | 98000. | 980000. | 6954. |
| .85 | .0063 | 696000. | 696000. | 186000. | 98000. | 980000. | 6206. |
| .90 | .0044 | 696000. | 696000. | 186000. | 98000. | 980000. | 4281. |
| .95 | .0035 | 696000. | 696000. | 186000. | 98000. | 980000. | 3471. |
| 1.00 | .0030 | 696000. | 696000. | 186000. | 98000. | 980000. | 2966. |
| | | | | | | R = | 109871. |

DIFFERENTIAL RATE = 3.00%
INTEREST RATE = 8.00%
INFLATION RATE = 5.00%

CM = 32700.
PVR = 59766.
TC = 92466.

NOTATION :

PGA = PEAK GROUND ACCELERATION IN G UNITS
NEI = NO. OF SEISMIC EVENTS BETWEEN PRIOR AND CURRENT PGA
D1 = STRUCTURAL & ARCHITECTURAL DAMAGE, N-S EARTHQUAKE
D2 = STRUCTURAL & ARCHITECTURAL DAMAGE, E-W EARTHQUAKE
D3 = ELECTRICAL & MECHANICAL EQUIPMENT DAMAGE
D4 = CONTENTS DAMAGE

DE = TOTAL DAMAGE PER EVENT
= (D1+D2)/2+D3+D4 WHERE (D1+D2)/2+D3+D4 < RC
TD = TOTAL DAMAGE IN THE PGA INTERVAL
= NEI*(PRIOR DE + CURRENT DE)/2
R = TOTAL COST OF FUTURE DAMAGE
RC = REPLACEMENT COST
CM = COST OF MODIFICATIONS
PVR = PRESENT VALUE OF COST OF FUTURE DAMAGE
ASSUMING DAMAGE SPREAD UNIFORMLY OVER 50 YEAR PERIOD
TC = TOTAL COST
= PVR + CM

cause the NEI values represent all seismic events expected to occur between the two successive PGA values and the damage is assumed to vary linearly between the two PGA levels. The total cost of repairs, R, is defined as the sum of the total damage costs, TD, for all the PGA levels.

(7) *Economic analysis.* The economic analyses for this example were performed assuming an interest rate, I, of 8 percent and an inflation rate, j, of 5 percent.

*(a) Existing building.* Table 7-2 indicates the repair cost analysis for the existing (unmodified) building. The results of the analysis are as follows:

| | |
|---|---|
| Total cost of repairs, R, | = $143,097 |
| Present value of cost of repairs, PVR, | = $ 77,839 |

*(b) Upgraded building.* Table 7-3 contains a similar repair cost analysis for the modified building as follows:

| | |
|---|---|
| Upgrading costs | = $ 32,700 |
| Total cost of repairs, R, | = $109,871 |
| Present value of cost of repairs, PVR, | = $ 59,766 |

*(c) Economic analysis*. The above roof analyses indicate that the present value of the anticipated repair costs of seismic damage to the building, over its useful life, will be $77,839 if the building is not upgraded. If the building is upgraded to compliance with the criteria of this manual, the present value of the anticipated repair costs will be reduced to $59,766, but the additional cost of $32,700, for the modification results in a total cost of $92,466. These total costs, with or without the upgrading modifications, are significantly less than the replacement costs of the building, equipment, and contents. Therefore, replacement need not be considered as an option.

(8) *Conclusions and recommendation.* The economic analysis indicates that upgrading this building is not cost-effective. The detailed structural analysis indicated that the existing building possessed adequate post-yield capacity to preclude collapse so that the life safety of the occupants is not in jeopardy. Therefore, unless there are other overriding considerations, seismic upgrading of this building should not be recommended.

## 7-8. Report

A report will be prepared for review by the approval authority and for formulating the decision as to whether the building should be upgraded, replaced, or left as is. In addition to the economic analysis, social, political, and administrative considerations will be addressed. These may include the impact of the potential seismic hazards on life safety of the occupants or to the public (e.g., collapse of a facility containing hazardous materials); current and future use of the building and its importance to the mission of the activity; costs associated with temporary interruptions of use during the upgrading and/or repair work; functionability of the existing building (e.g., are there functional problems that could be corrected during the upgrading work?); and the historic significance of the building. A discussion of these and other appropriate considerations will be included in the report with a qualitative evaluation applicable to each building in support of recommendations that will be made as to action to be taken for each building.